



***Conformal Membrane Reflectors  
for  
Deployable Optics***

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23 May 2002



- Company Introduction
- Program Outline
- Results
- Related CRG Technology
- Summary



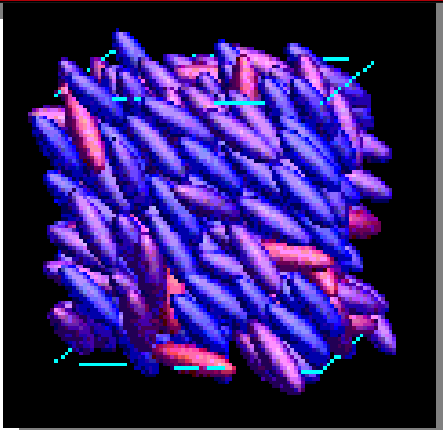
**CRG specializes in  
research and development  
of advanced materials and  
process technologies to  
enhance our customers'  
competitiveness.**

- Founded April 1997 to conduct applied R&D of novel polymeric materials
- Bootstrapped: No partners or outside investors
- First commercial contract awarded February 2001 (35% of sales)

# Company History

## Optical Materials (1997-present)

### Latching Electrooptic Liquid Crystals



### Reflective Membranes



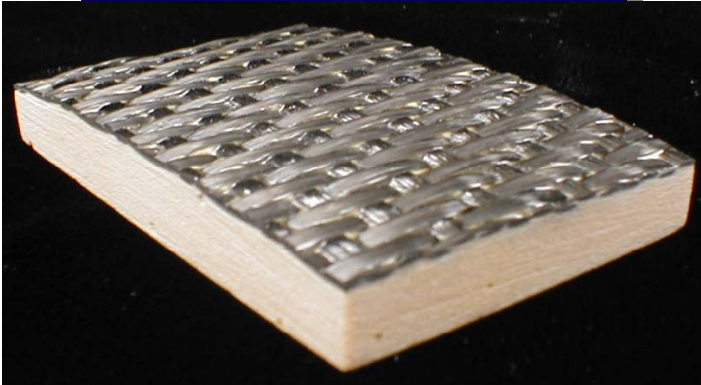
### Composite Mirrors



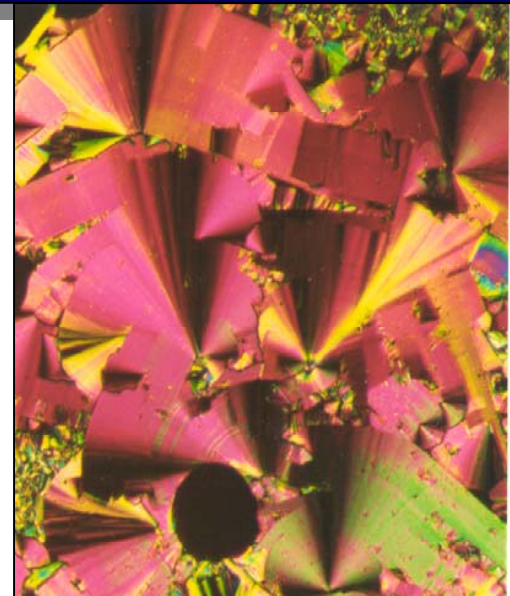
# Company History

## *Structural Materials (1998-present)*

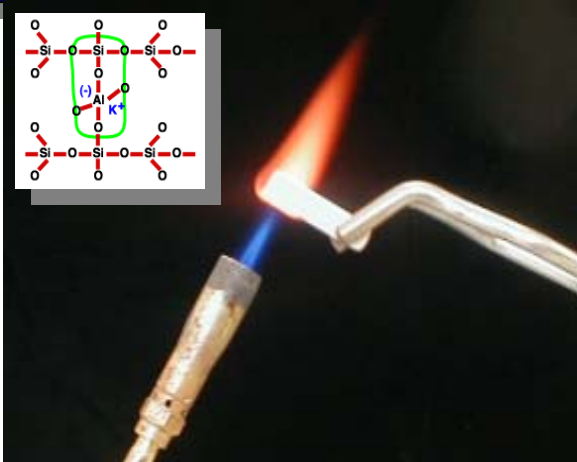
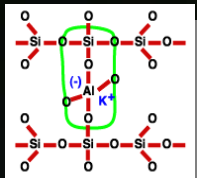
### Syntactics



### Reactive Liquid Crystals

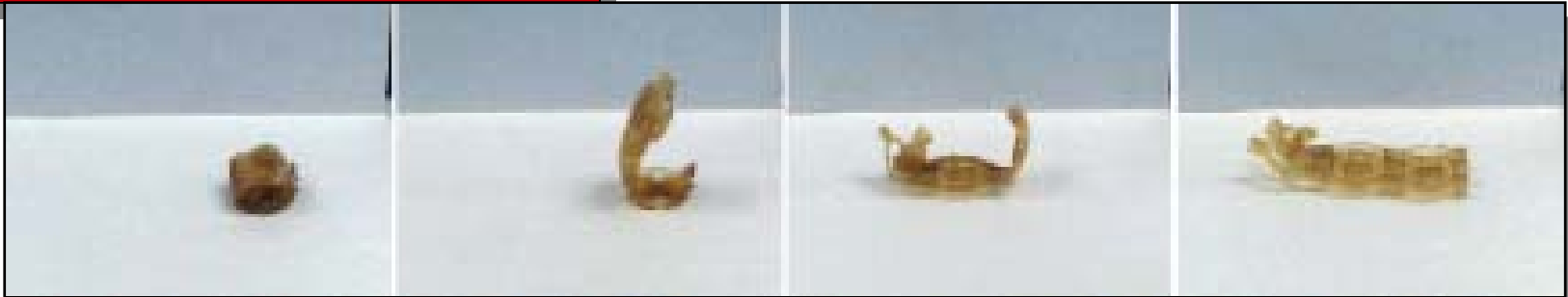


### Inorganic Resins





### Shape Memory Polymers



### Dynamic Modulus Composites



# Technology Development Market Driven

## Aerospace



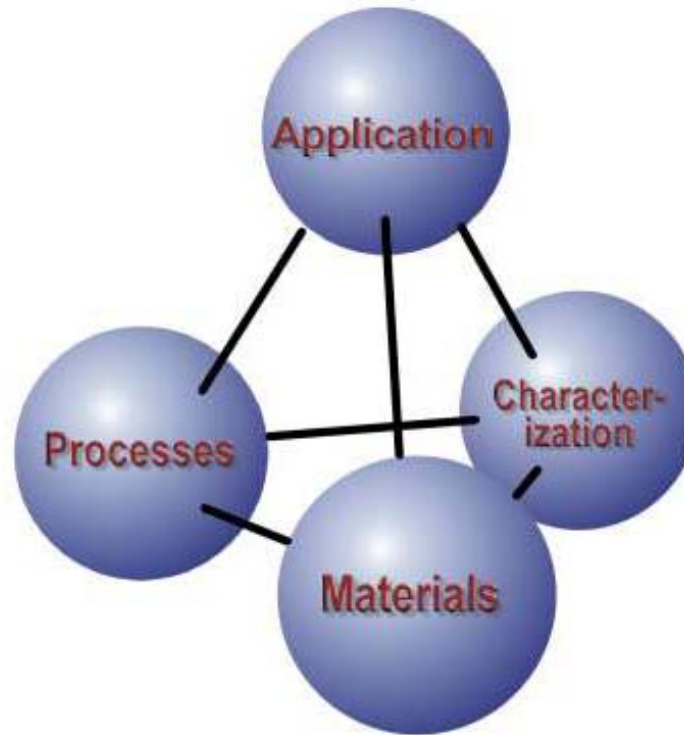
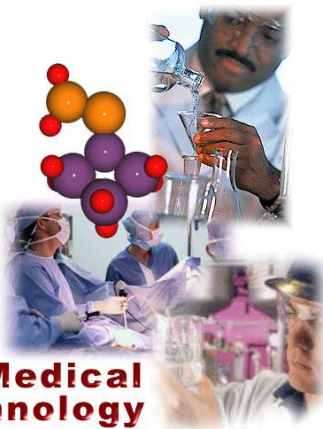
## Industrial Applications



## Space



## Medical Technology



## Military Applications



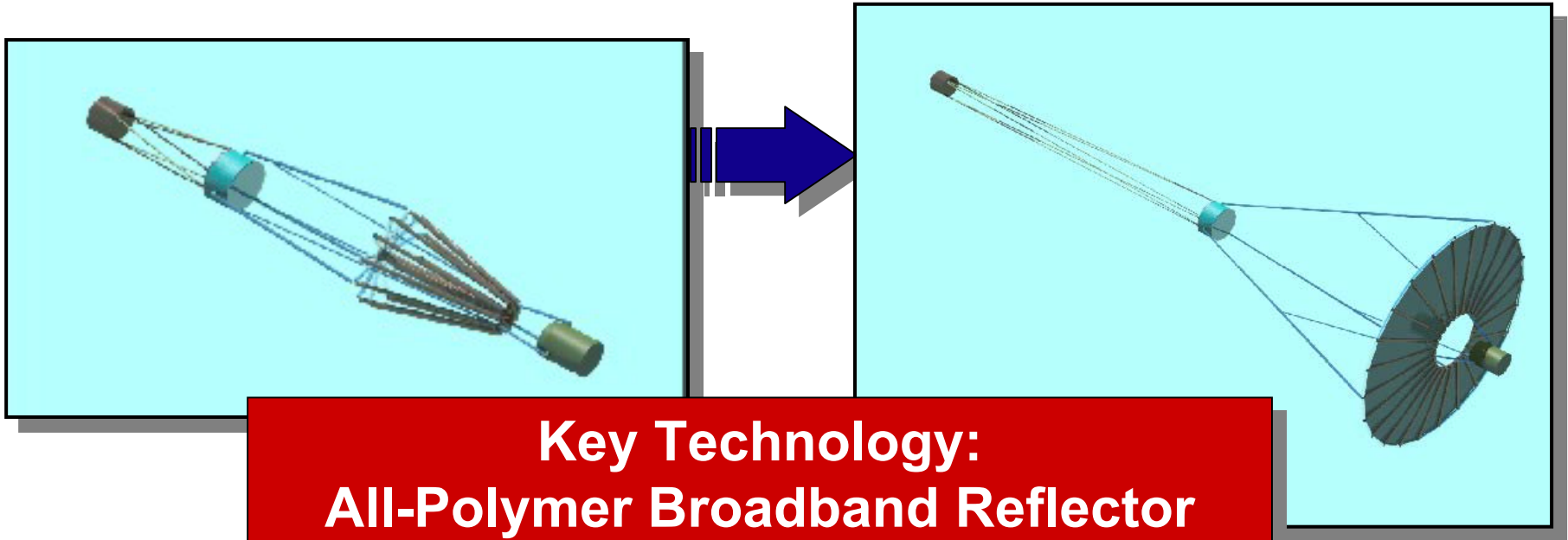
**Technology Matched with Customer Needs**



- 21,000-ft<sup>2</sup> Facility
- Capabilities
  - Polymer synthesis, formulation, & characterization
  - Composite processing & characterization
  - Interference microscope for surface characterization
  - Clean room
  - Laboratory automation & control using LabView software



# Requirement: Large Membrane Optics



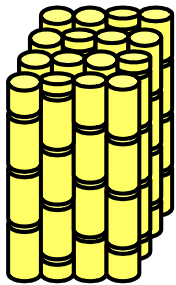
## Key Technology: All-Polymer Broadband Reflector

- Thermal Stability
- Low Areal Density
- High Specular Reflectivity
- Broad Bandwidth
- Radiation Hard
- Mechanically Robust

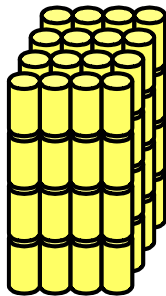
# Chiral Liquid Crystal Reflectors

## Classes of LC Order

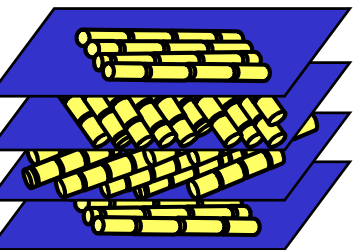
*Nematic*



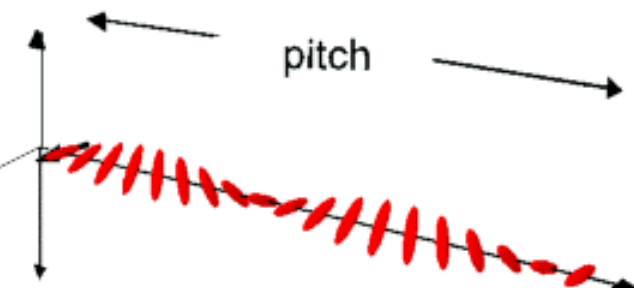
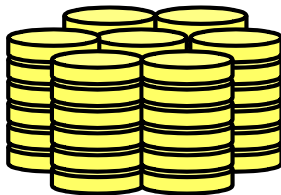
*Smectic*



*Cholesteric*

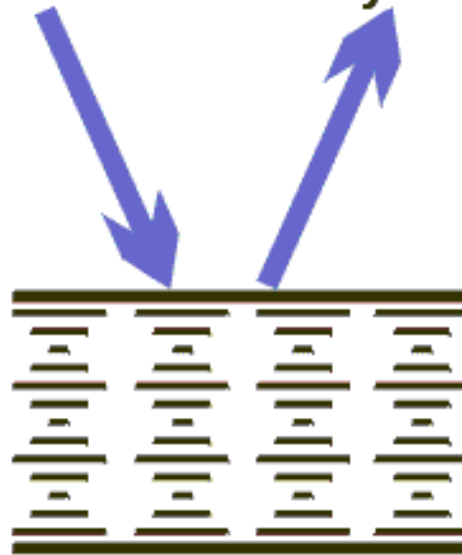


*Discotic*

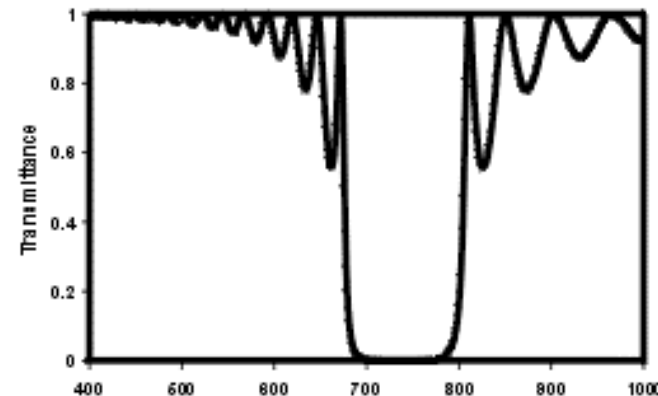
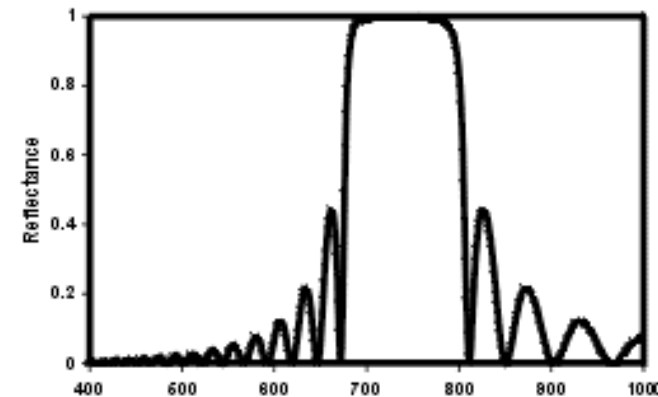


## Chiral Optical Characteristics

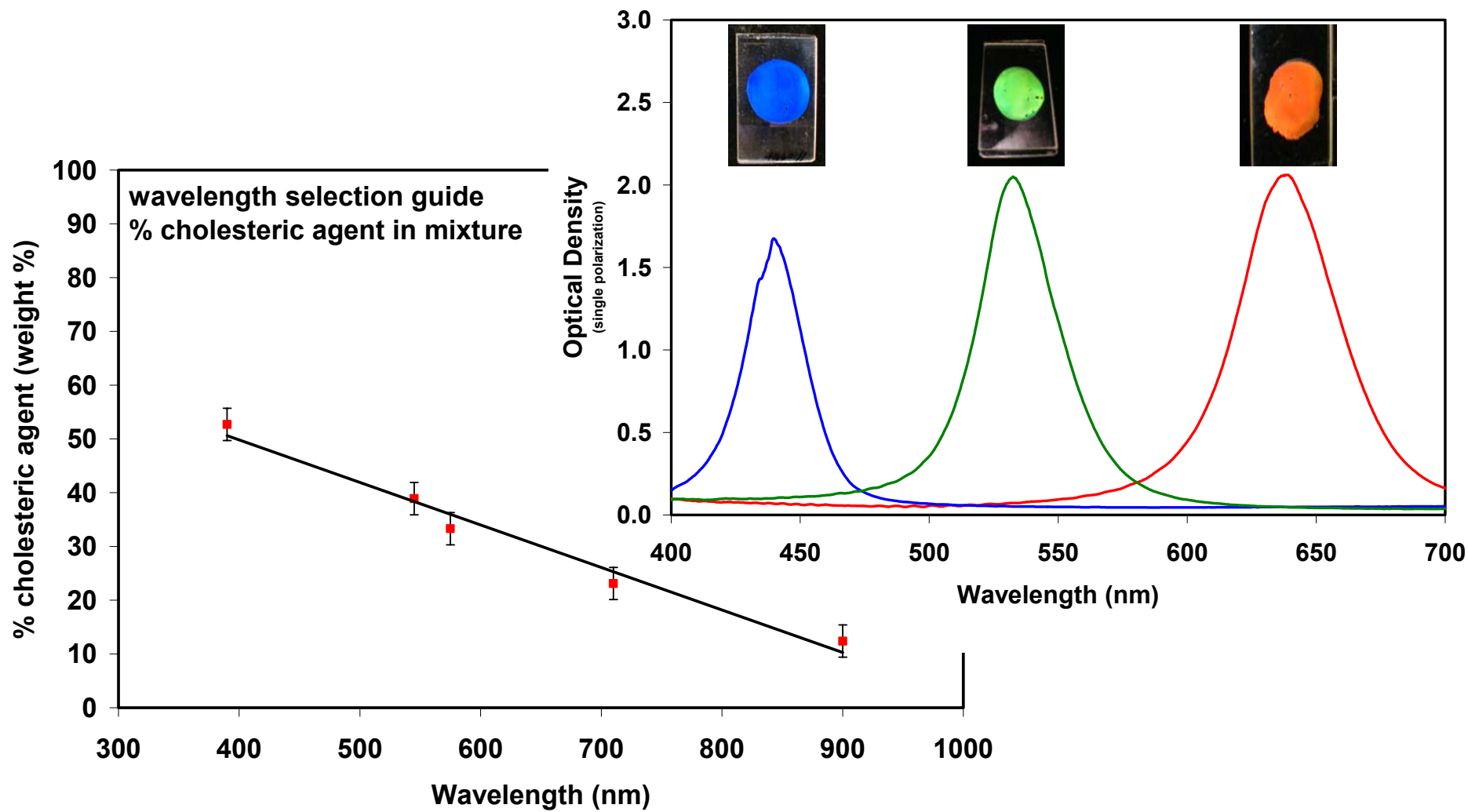
**Reflected Light:  
Right-Handed  
Circularly Polarized**



**Transmitted Light:  
Left-Handed  
Circularly Polarized**

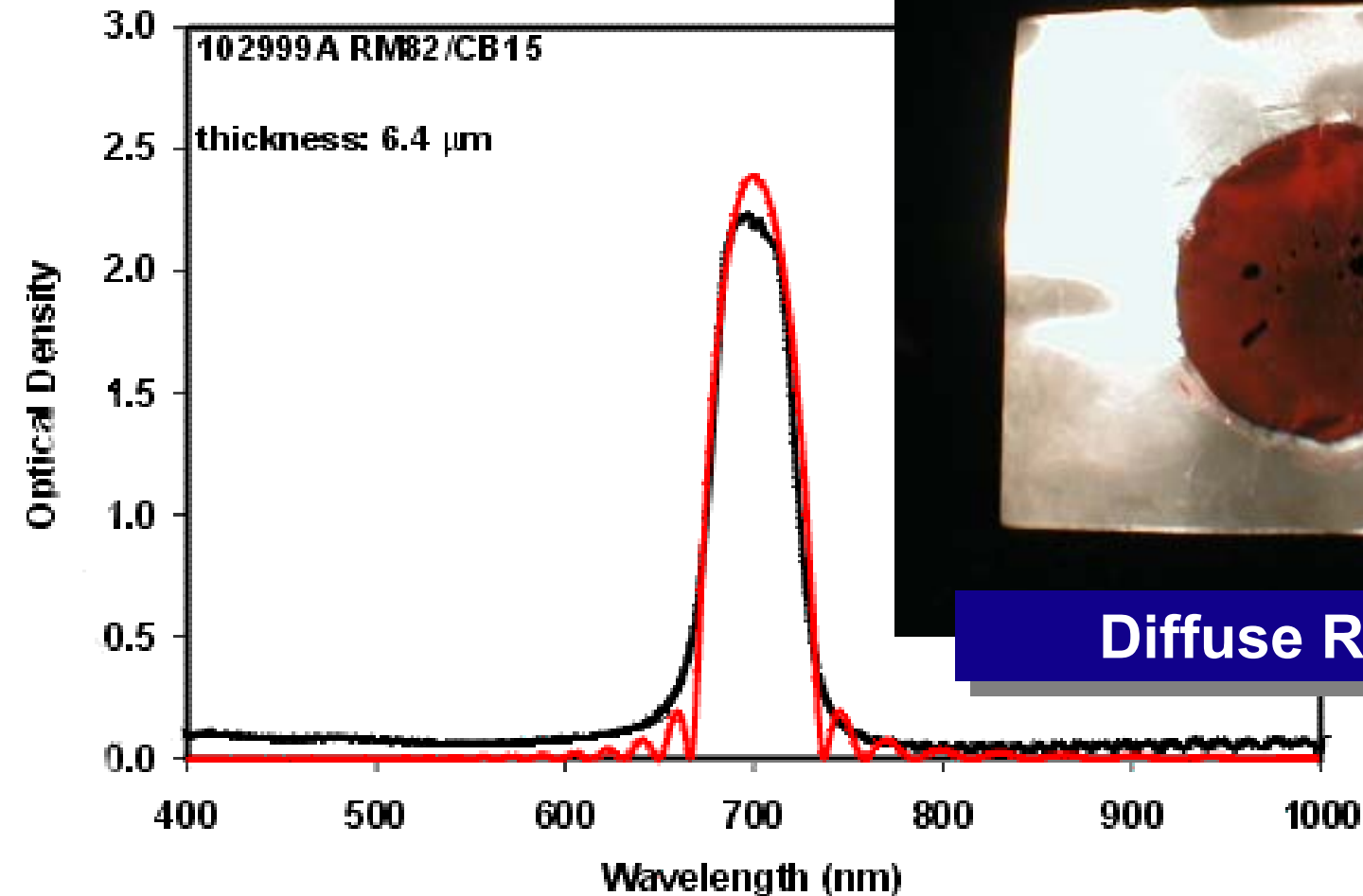


# Wavelength Selection



**Composition Controls Wavelength**

# Free-Standing Membranes

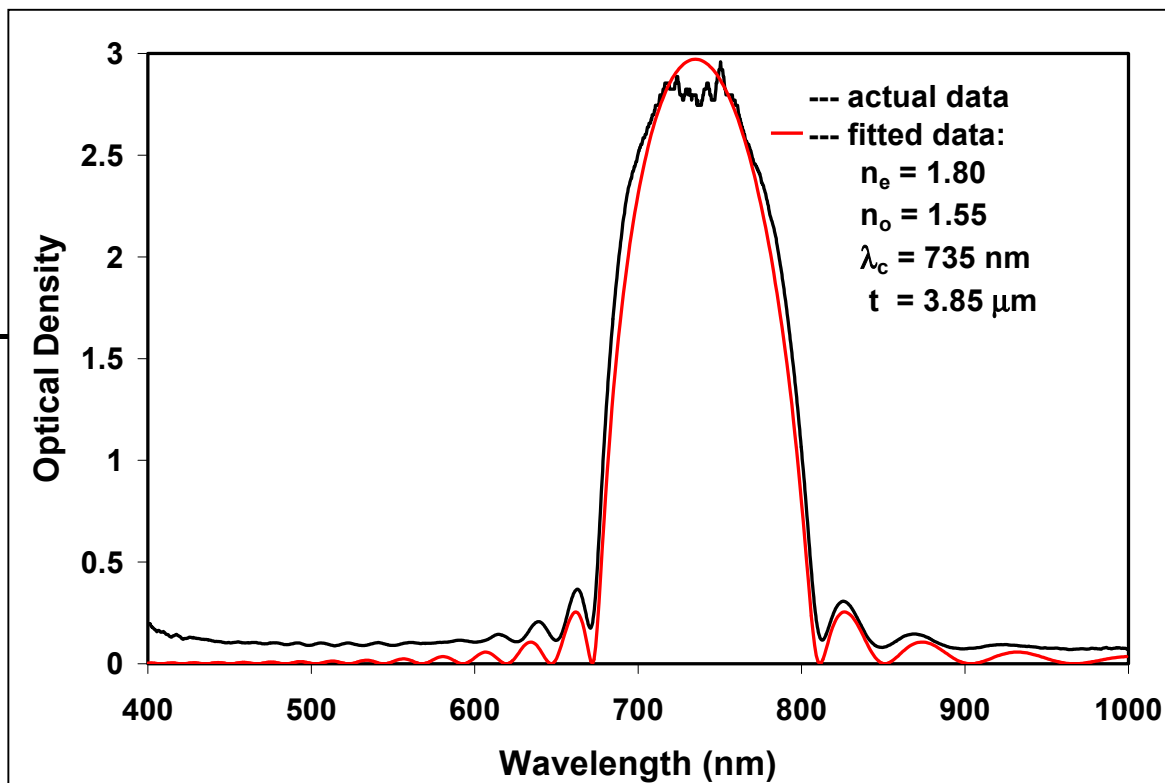
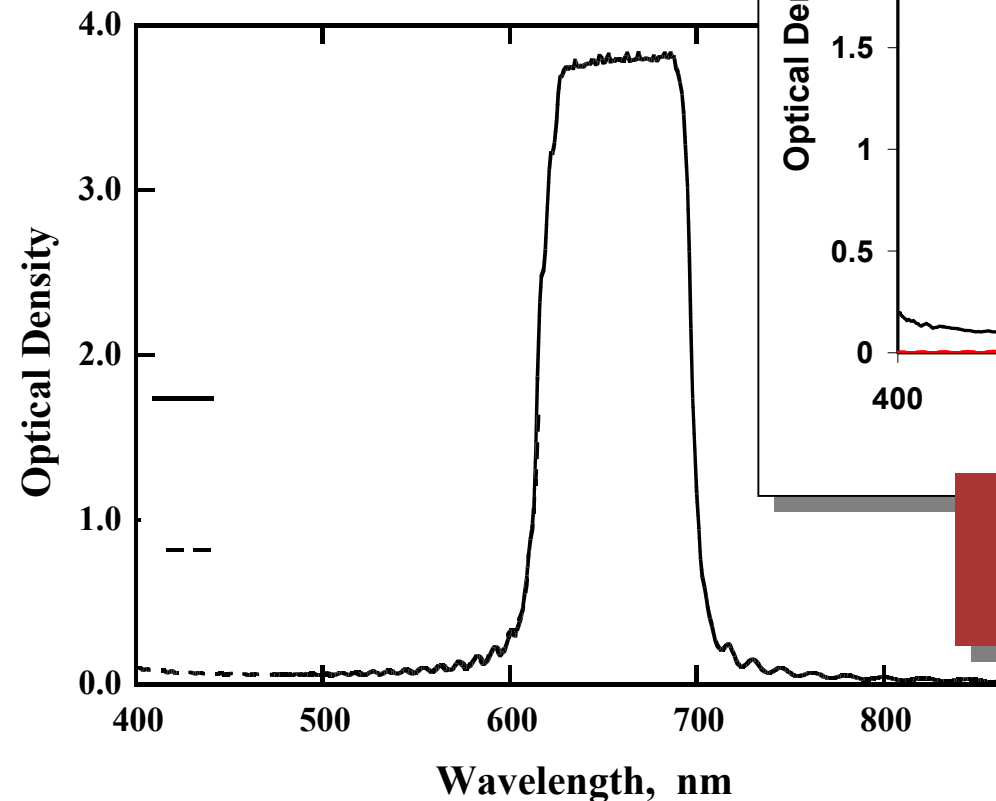


**Diffuse Reflector**



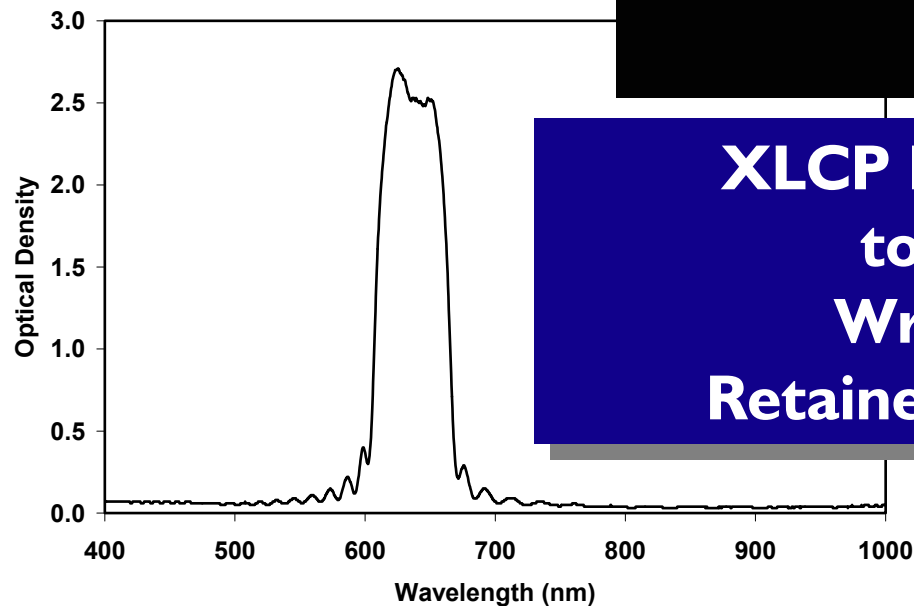
# Polymer Reflector Performance

**High Optical Densities  
Achieved**



**Experimental Performance  
Correlates Well with Theory**

# Conformal Processing



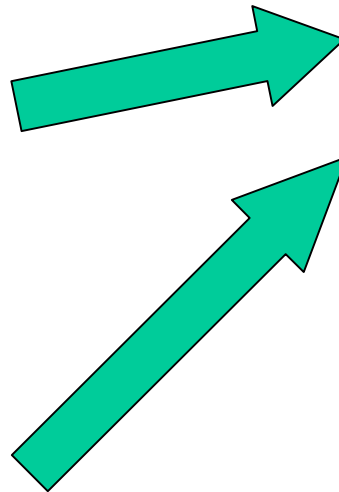
**XLCP Membrane Conformed  
to Parabolic Figure:  
Wrinkle-Free Surface  
Retained Optical Performance**

# Program Objectives

## Phase I Coupon Scale LCP Devices

**LCP Film,  
Monodomain  
Broadband  
Reflector**

**LCP Membrane,  
Monodomain  
Narrowband  
Reflector**



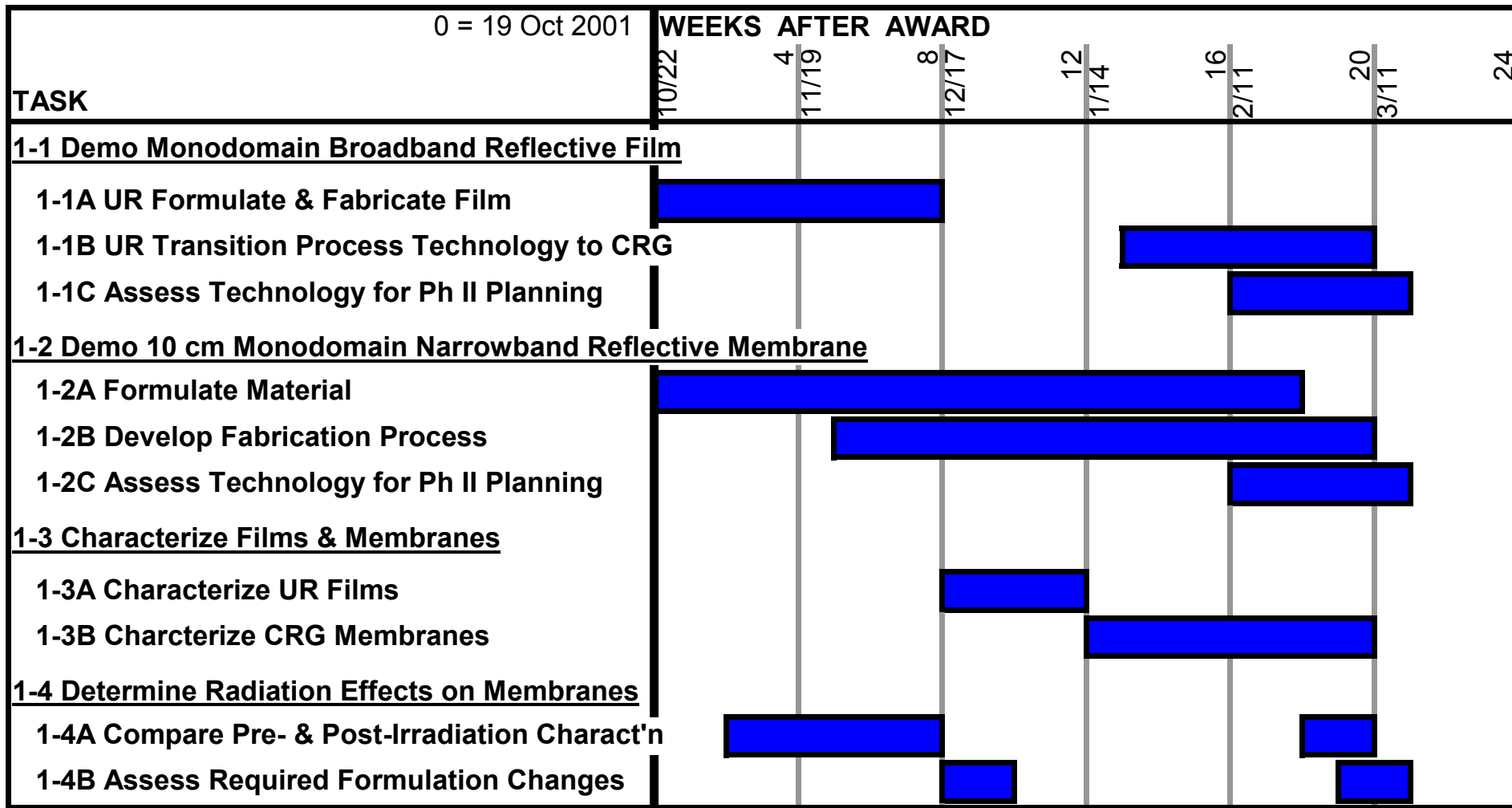
## Phase II Prototype Mirror

**LCP Membrane,  
Monodomain  
Broadband Reflector:  
Coupon**



**LCP Membrane,  
Monodomain  
Broadband Reflector:  
1 m Prototype Mirror**

# Phase I Work Plan

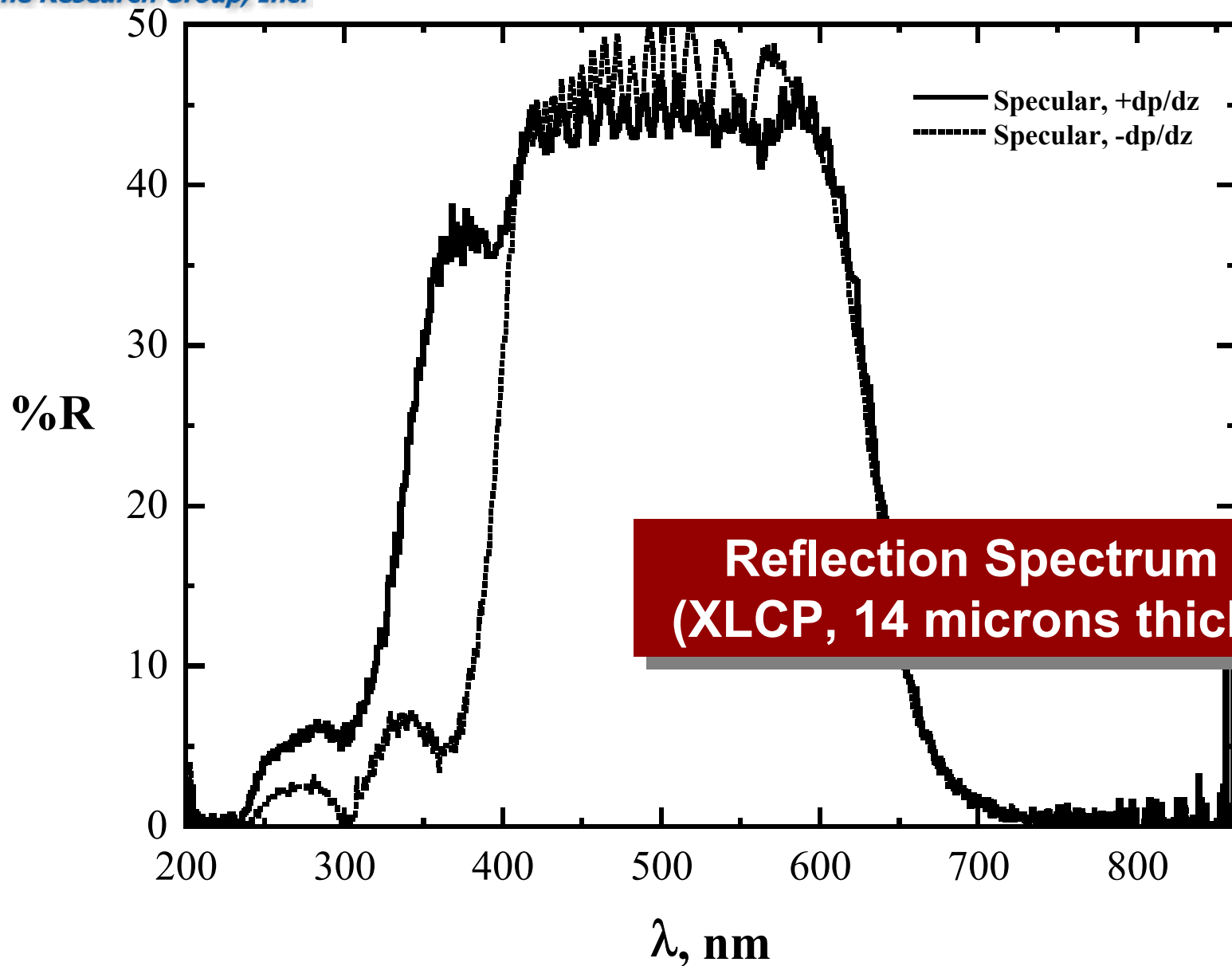


## Task 1-1: Monodomain Broadband Film

- University of Rochester effort -- Prof Shaw Chen
- Developed monodomain LCP broadband reflective film
  - Cross-linked cholesteric LCP
    - Formulated with commercially available monomers
    - Polymerization yields graded pitch of molecular structure -- broadening the reflection band
  - Homogenous film with good alignment
  - Transitioned fabrication process technology to CRG
- **Achieved broadband specular reflectance**  
Reflectance near theoretical maximum of 50% for single layer material

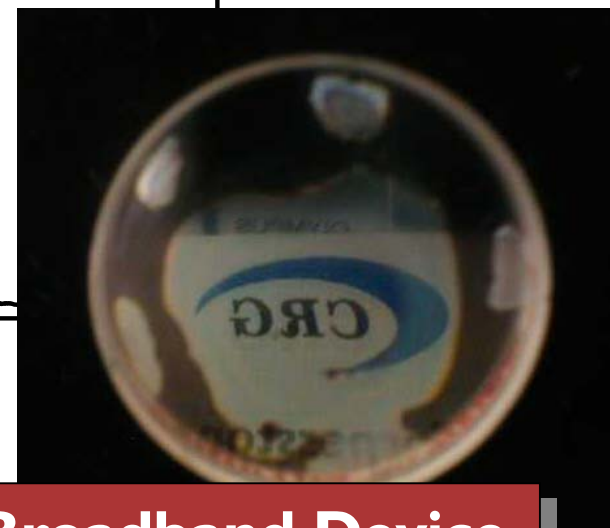
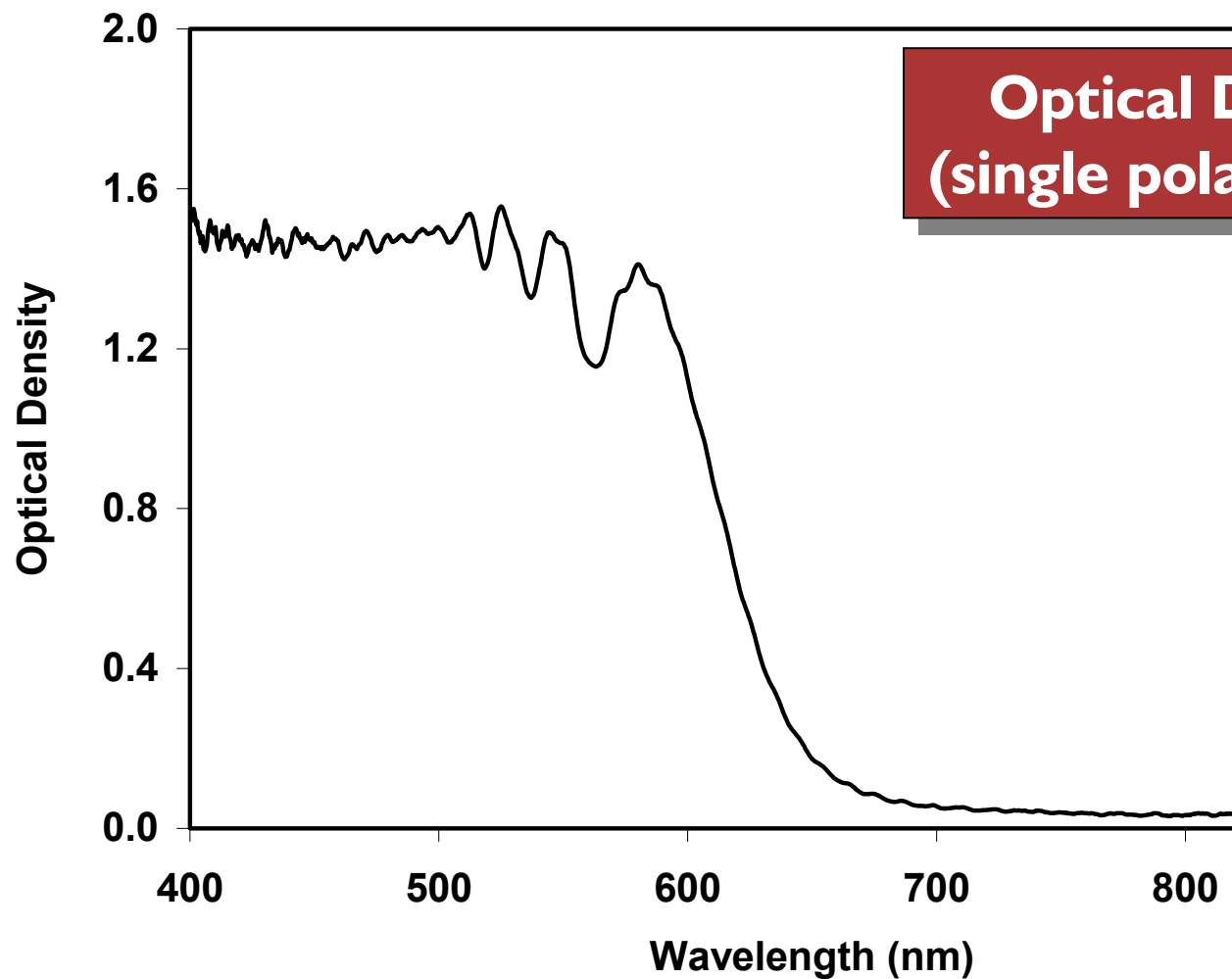


# Task 1-1: Monodomain Broadband Film



**Reflection Spectrum  
(XLCP, 14 microns thick)**

# Task 1-1: Monodomain Broadband Film



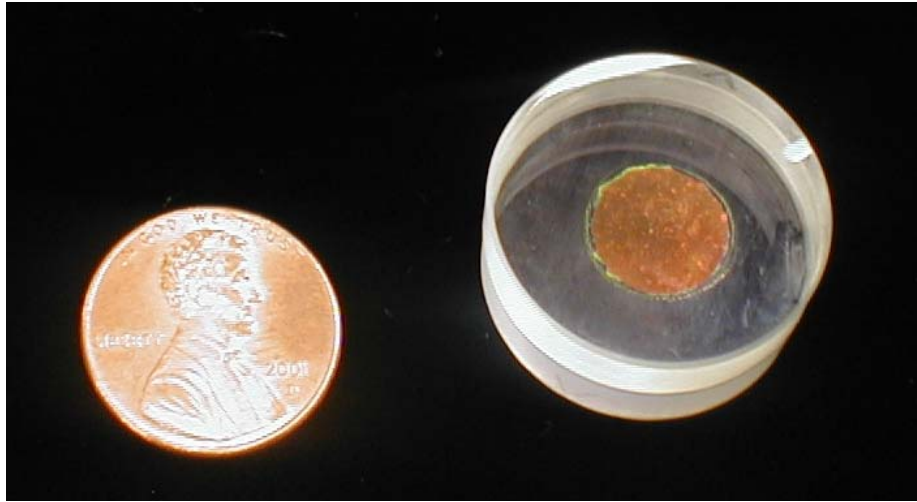
**Specular Reflection in Monodomain Broadband Device  
(XLCP film on 2.5 cm diameter glass substrate)**

## Monodomain Narrowband Membranes

- Developed monodomain LCP narrowband reflective membrane
  - Cross-linked cholesteric LCP formulated with commercially available monomers
  - Photopolymerization process
  - Homogenous material with good alignment
- Developed process for releasing membrane
- **Achieved narrowband specular reflectance in free-standing membranes**

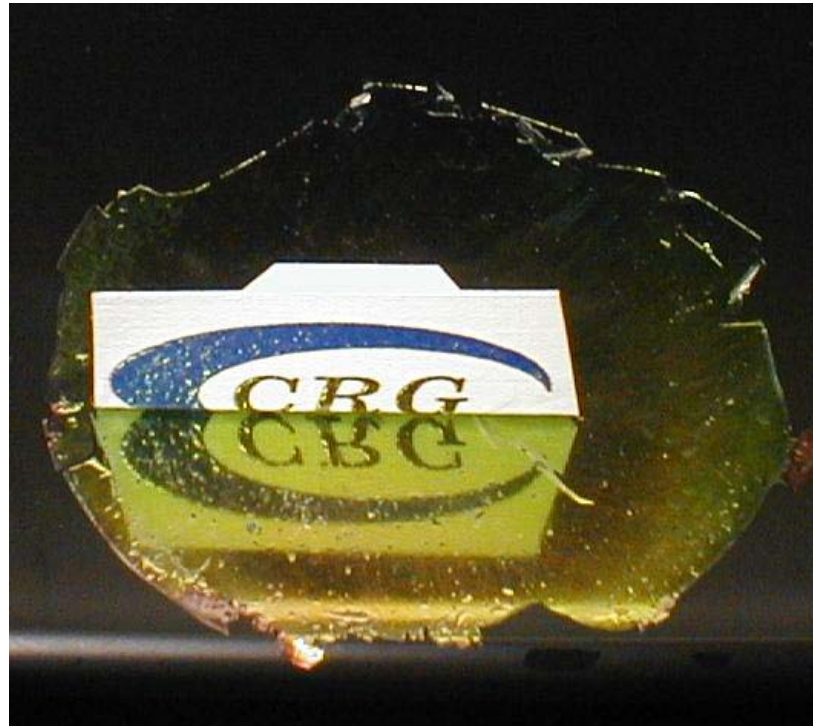
Reflectance near theoretical maximum of 50% for single layer material

# Task 1-2: Monodomain Narrowband Membranes



**Cured XLCP Material  
Before Release from Glass Substrate**

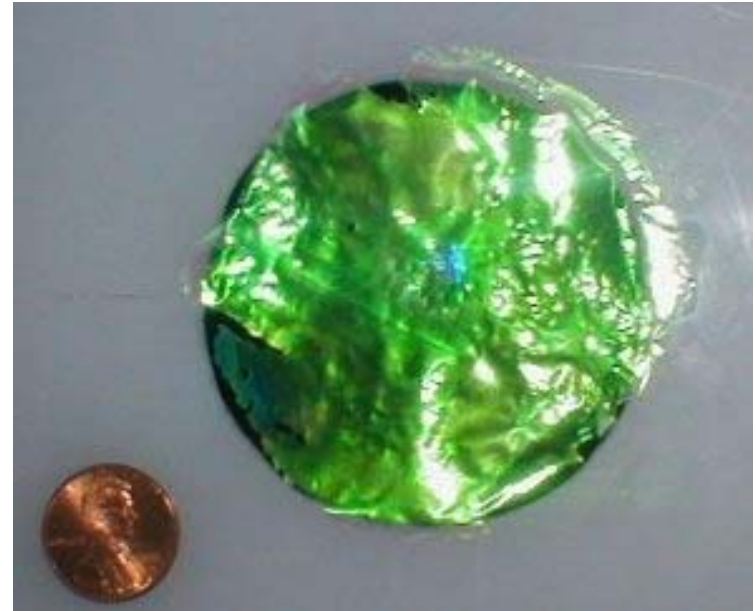
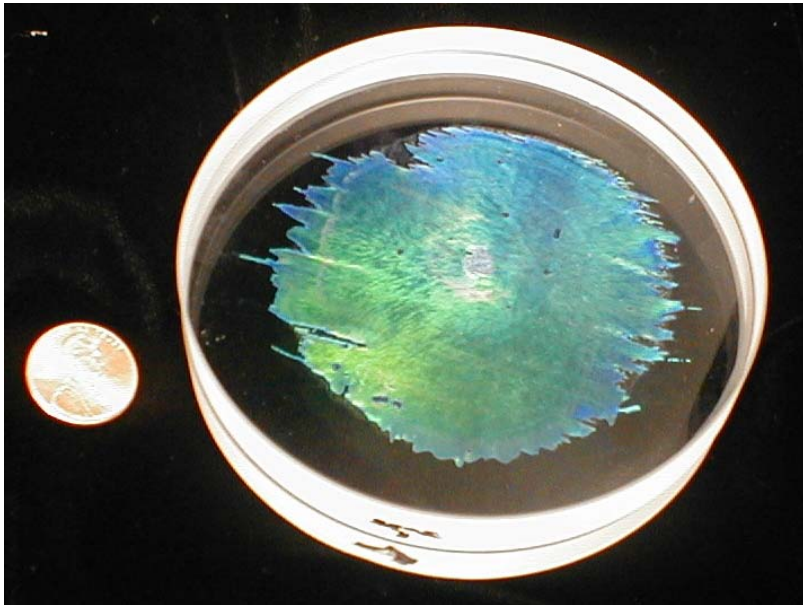
# Task 1-2: Monodomain Narrowband Membranes



**XLCP Membrane  
After Release from Glass Substrate  
(4.5 cm diameter, 13 micron thickness)**

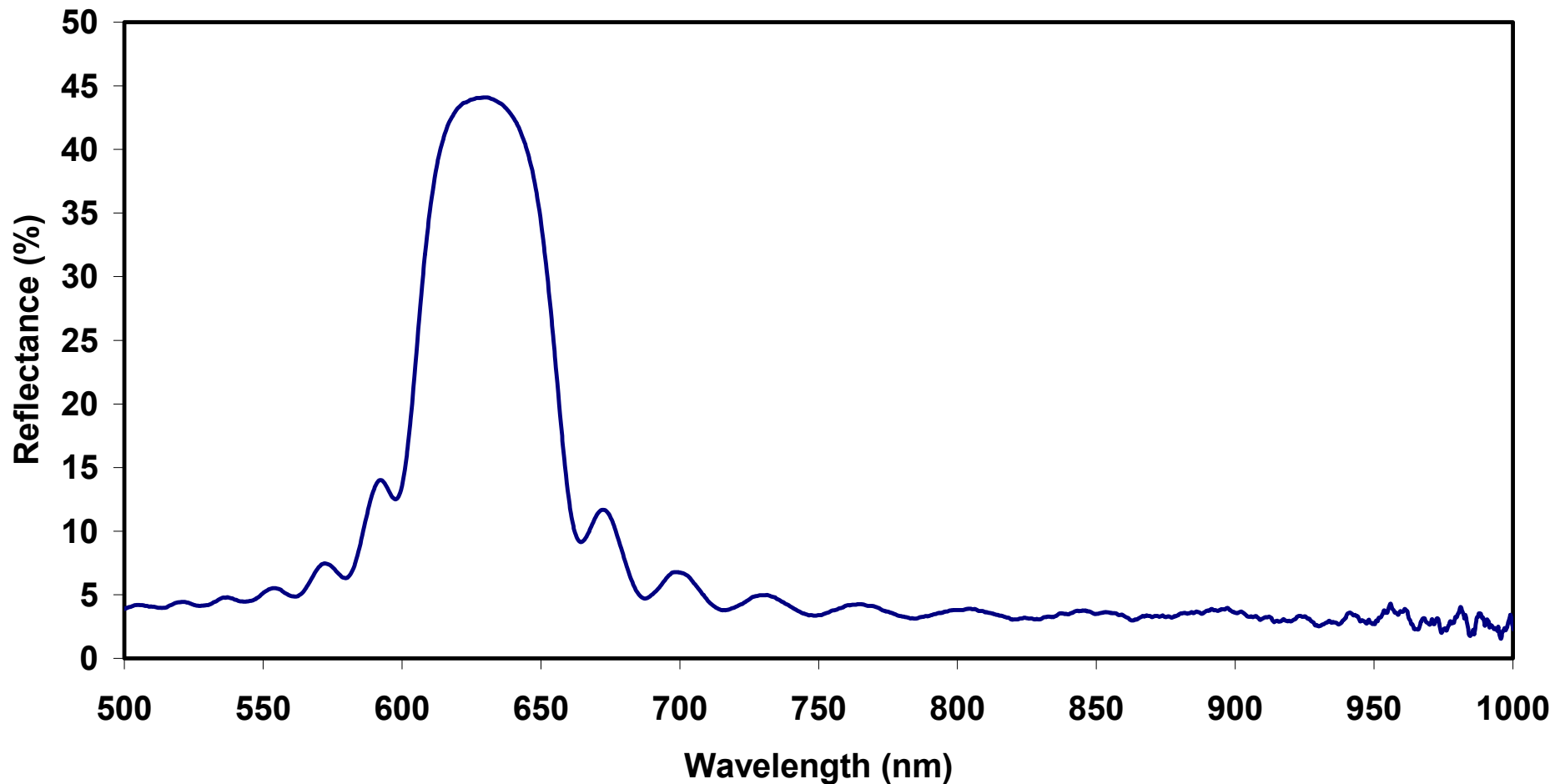


# Monodomain Narrowband Membranes



**XLCP Membrane  
Before (L) & After (R) Release from Glass Substrate  
(7.5 cm diameter, 13 micron thickness)**

# Task 1-2: Monodomain Narrowband Membranes

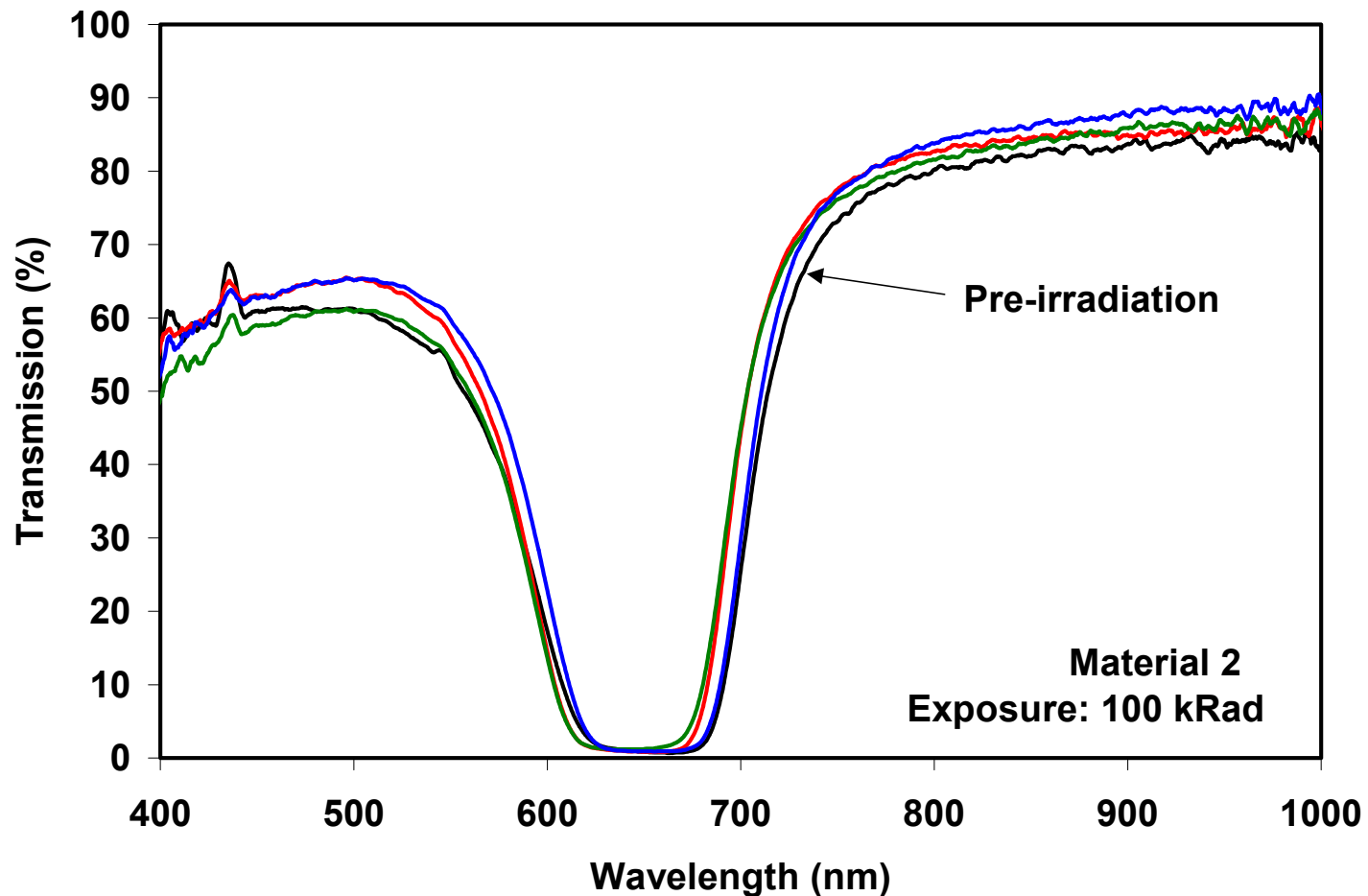


**Reflectance of LCP Narrowband Membrane**

## Task 1-4: Determine Radiation Effects

- International Photonics Consultants, Inc., accomplished gamma irradiation tests
  - Used polydomain narrowband XLCP material as analog to monodomain materials
    - Timing required radiation test before monodomain material would be available
    - Chemical compositions closely related
  - Exposures: 10 krad, 50 krad, 100 krad
  - Pre- & Post-Irradiation characteristics compared
- Results: Small radiation effect requiring further study

# Task 1-4: Determine Radiation Effects



**Transmission of Polydomain Device  
Before & After Gamma Irradiation**

- Company Introduction
- Program Outline
- Results
- Related CRG Technology
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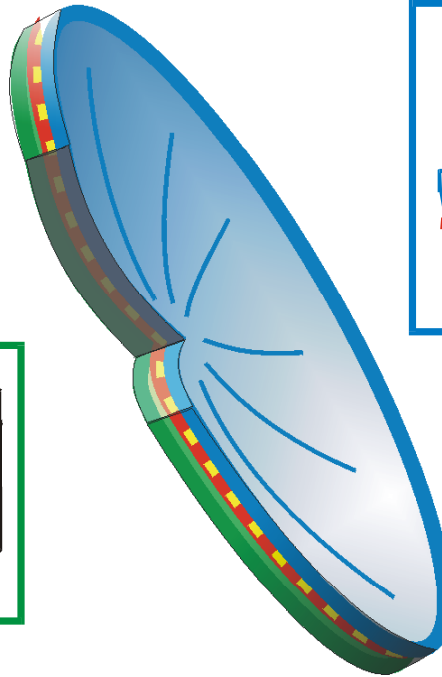


# NRO 2001 DII Program Overview

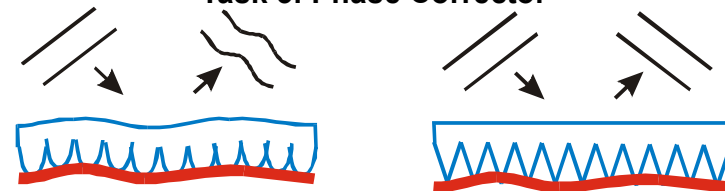
## Task 1: Deployable EM Reflector



*Rolled SMP reflector unfurls to near-net shape.*

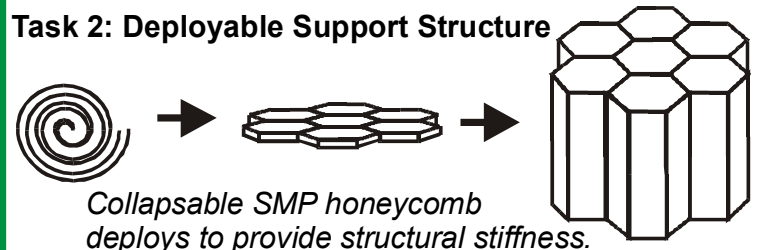


## Task 3: Phase Corrector



*Shape Memory Polymer optical phase corrector provides post-deployment wavefront correction.*

## Task 2: Deployable Support Structure



*Collapsible SMP honeycomb deploys to provide structural stiffness.*

## Task 4: Integrated Active Damping

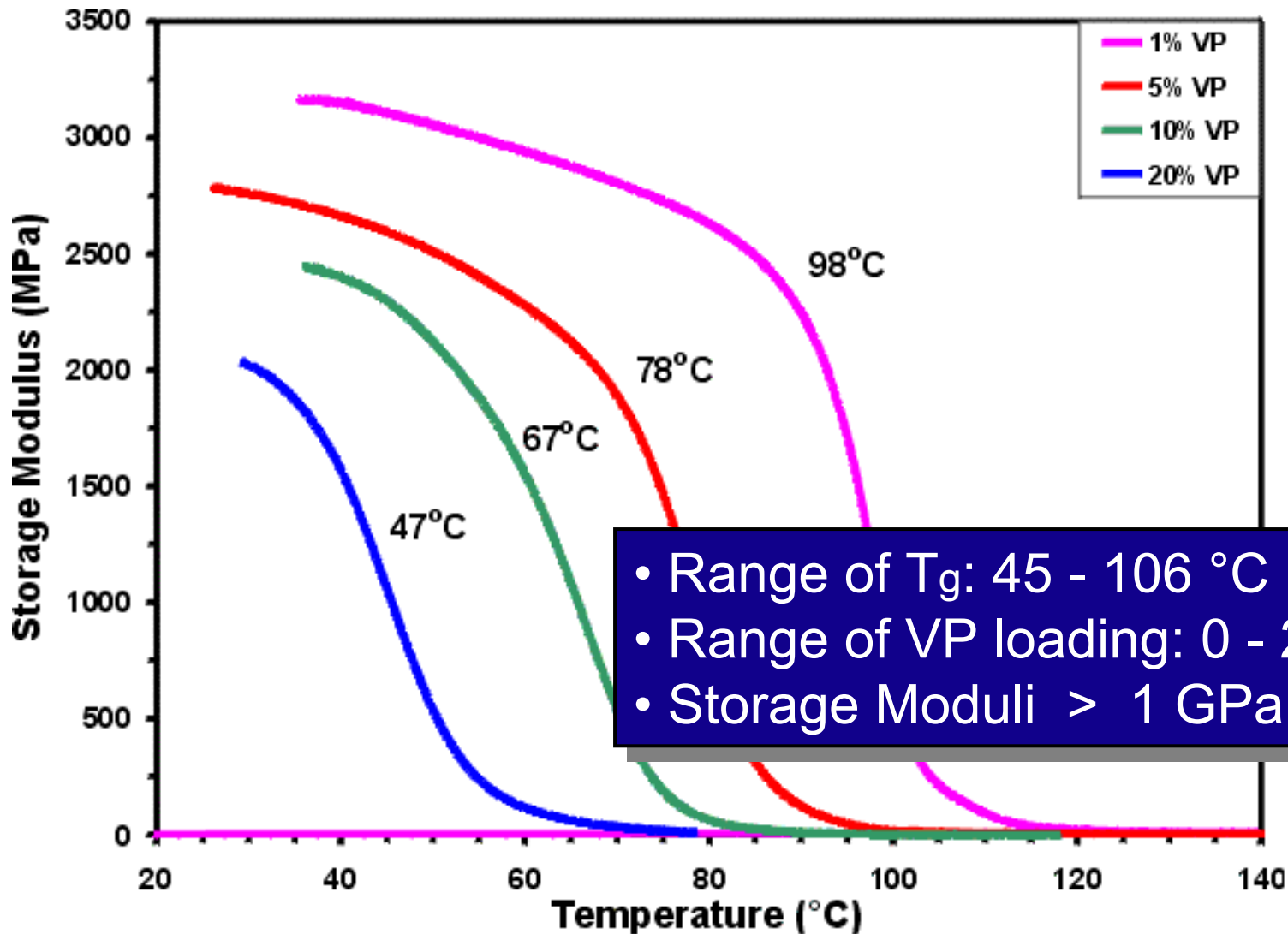


*PVDF devices distributed within deployable EM reflector provide active damping of vibrations over broad frequency ranges.*

## Program Goal

Use strain recovery property of **Shape Memory Polymers** to achieve self-deployable high-performance, phase corrected optical sensors for space applications

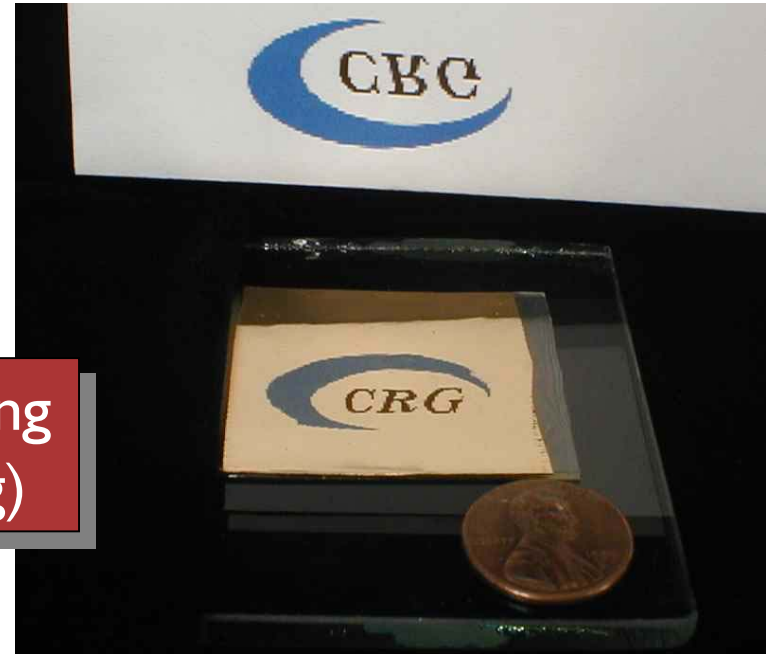
# Tailoring SMP Mechanical Properties





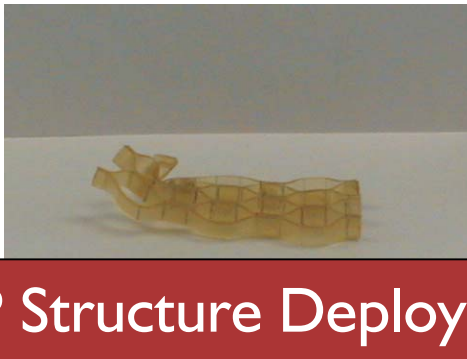
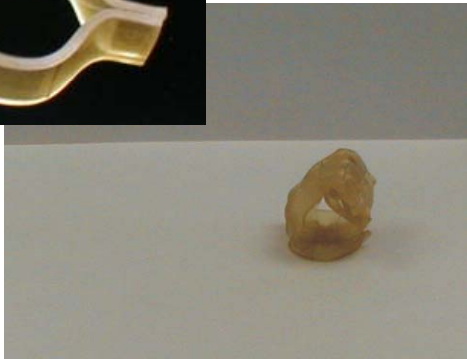
Styrene-Based SMP Reflector with Gold Coating  
(12.7cm dia, 2.5cm thickness,  $\approx 400 \text{ \AA}$  coating)

SMP Reflector with Gold Coating  
( $\sim 1$  mm thick,  $\approx 400$  Å coating)



SMP Activation Sequence (approximately 1 minute)

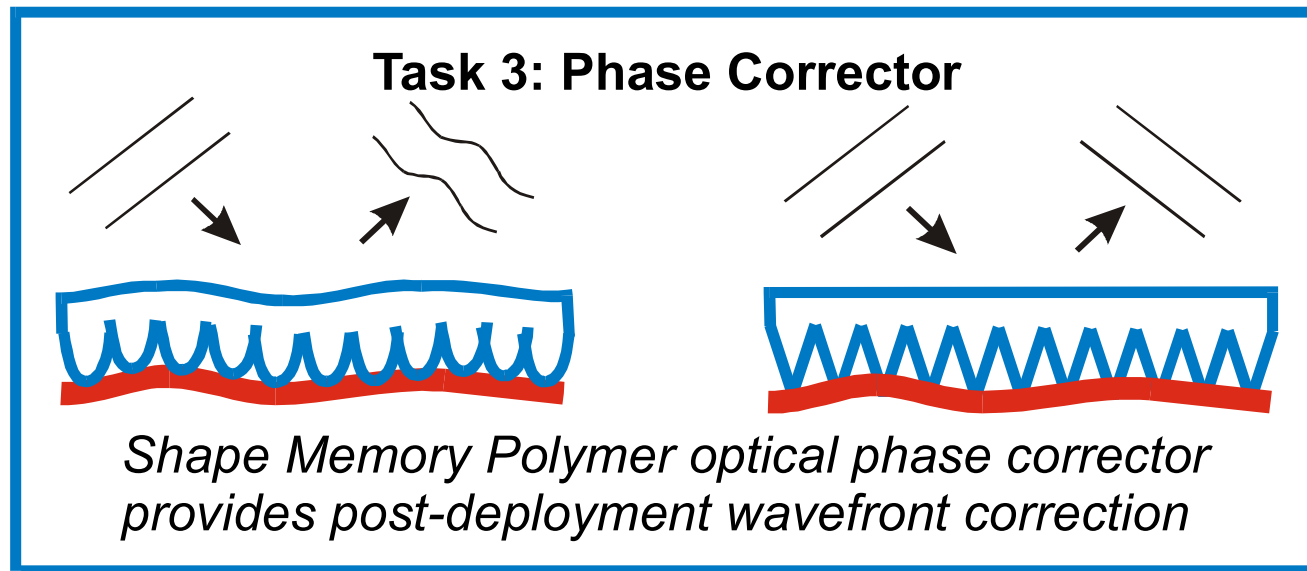
## Compression Molded SMP



SMP Structure Deployment  
(approximately 30 seconds)

- Goal:

Design and demonstrate microactuator array to correct for post-deployment wavefront distortion



- Approach:

Microstructure SMP arrays actuated via laser diode

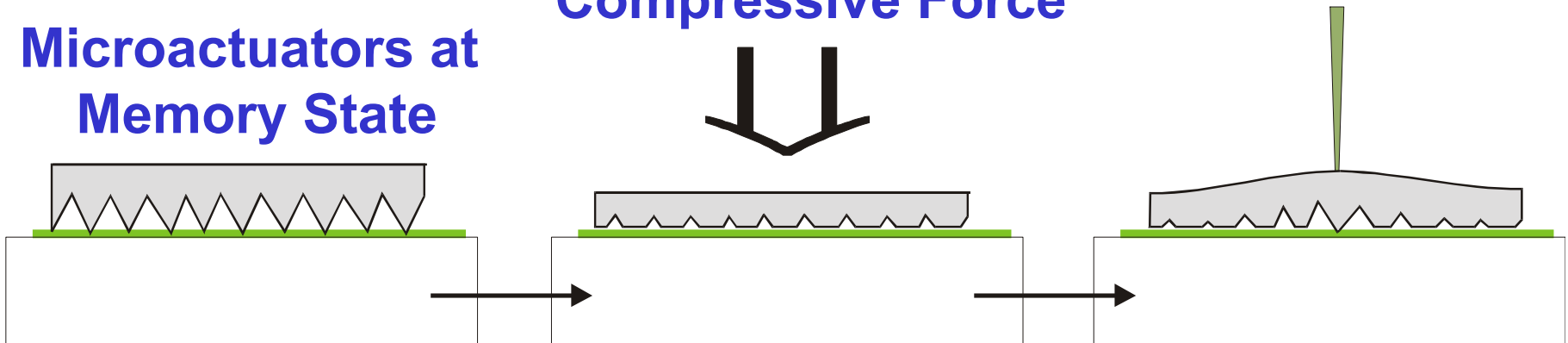
## Experimental Approach

- Design SMP & dye
- Fabricate microactuator array
- Compress
- Actuate with laser diode

**Microactuators at  
Memory State**

**Compressive Force**

**Laser Radiation  
Activates Individual  
Microactuators**



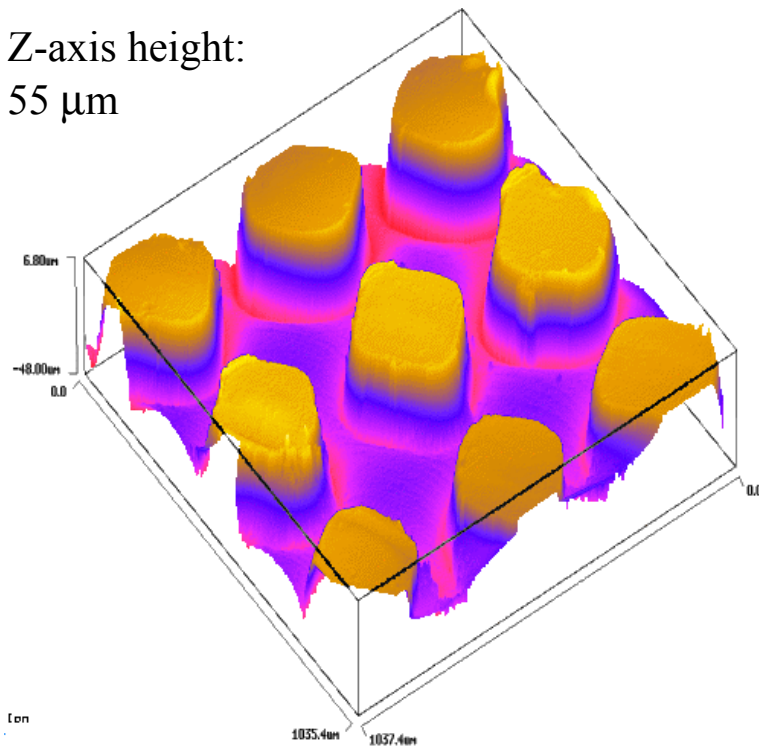


X-Y window size:

1 mm x 1mm

Z-axis height:

55  $\mu\text{m}$



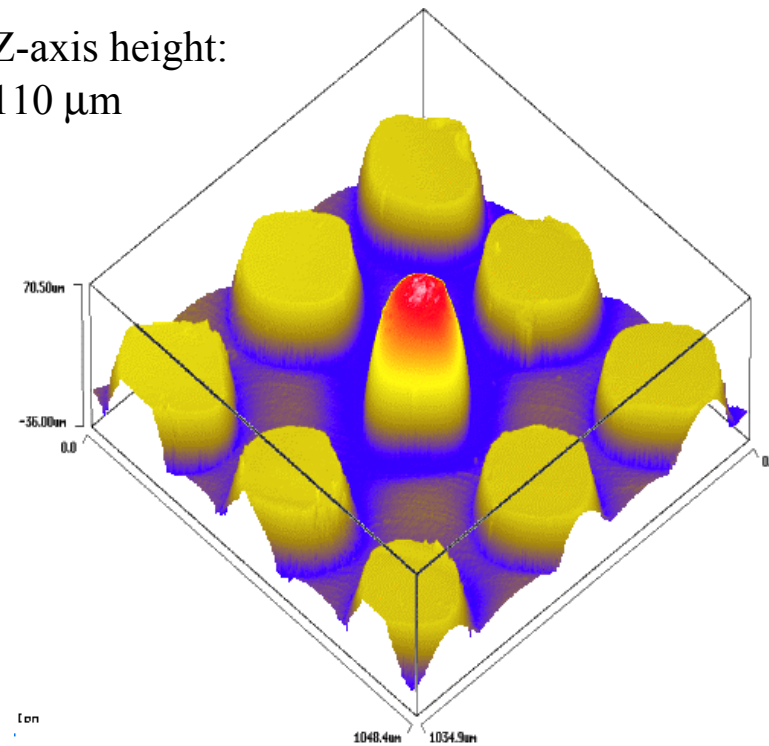
Phase Corrector with Partially  
Flattened Microactuators

X-Y window size:

1 mm x 1mm

Z-axis height:

110  $\mu\text{m}$

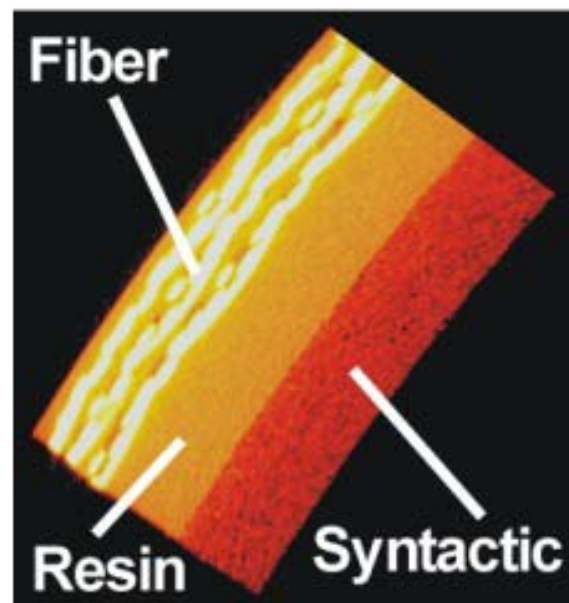


Phase Corrector with Single  
Activated Microactuator

# Multi-Functional Composites

## Features

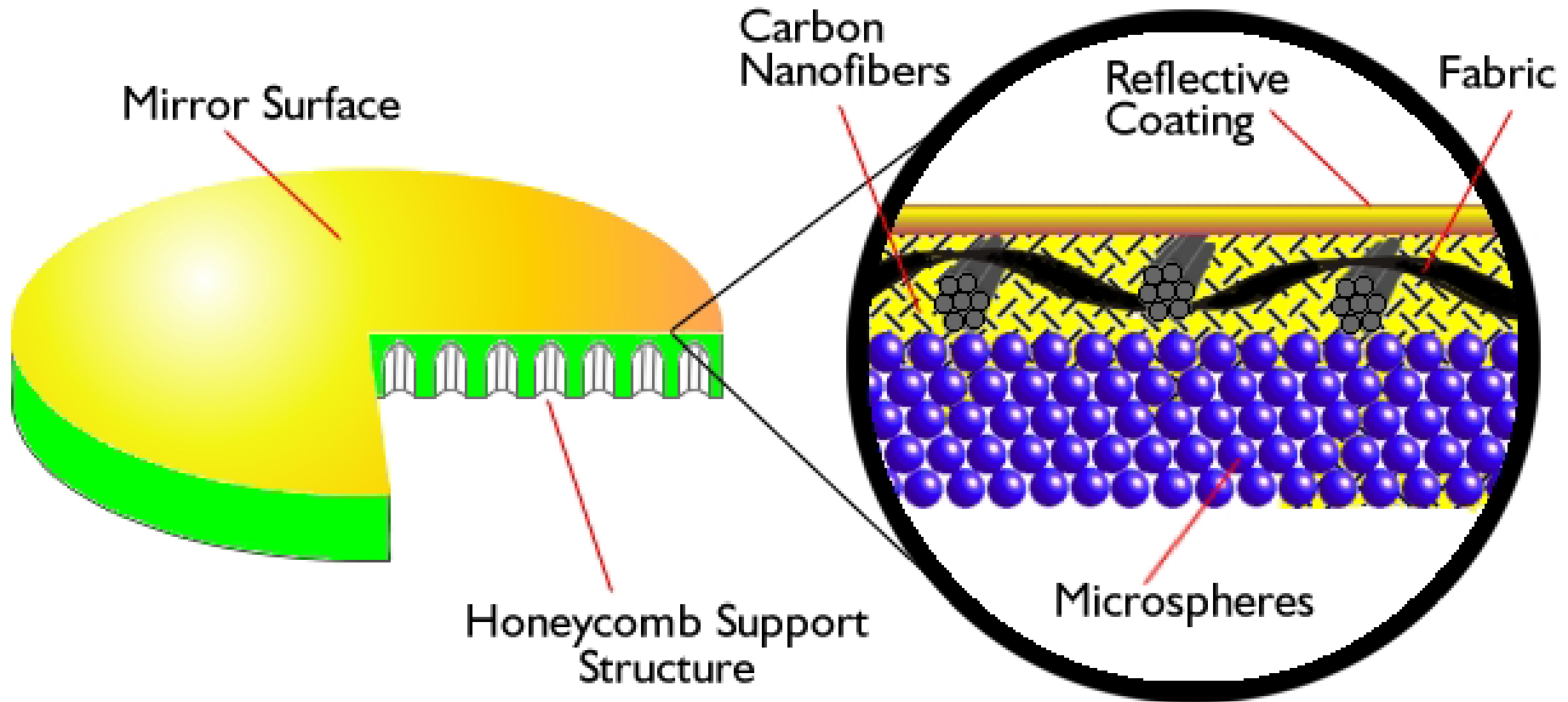
- Automated process
- Multilayer, multicomponent
- Advanced materials
- Increased design flexibility



## Applications

- Solid rocket motors
- Radomes
- Limited collateral damage weapons

# Composite Mirrors



**Air Force 2002 SBIR Phase I**

# High-Performance Syntactic Composites



## Features

- 0.55 g/cc
- High specific strength
- Superior integrity

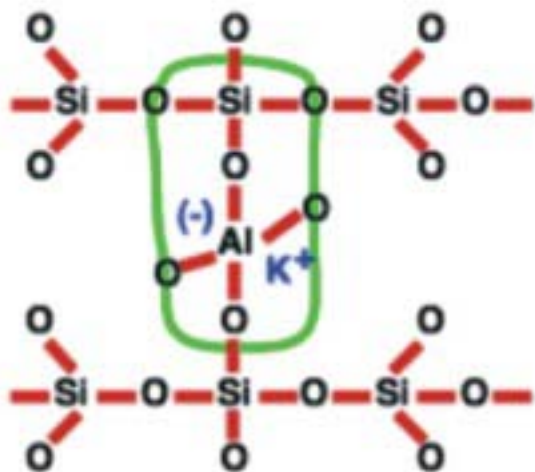
## Applications

- Strong lightweight spacers
- Insulatory propulsion components
- Missile radomes



Cornerstone Research Group, Inc.

# Inorganic Resin: Polysialate



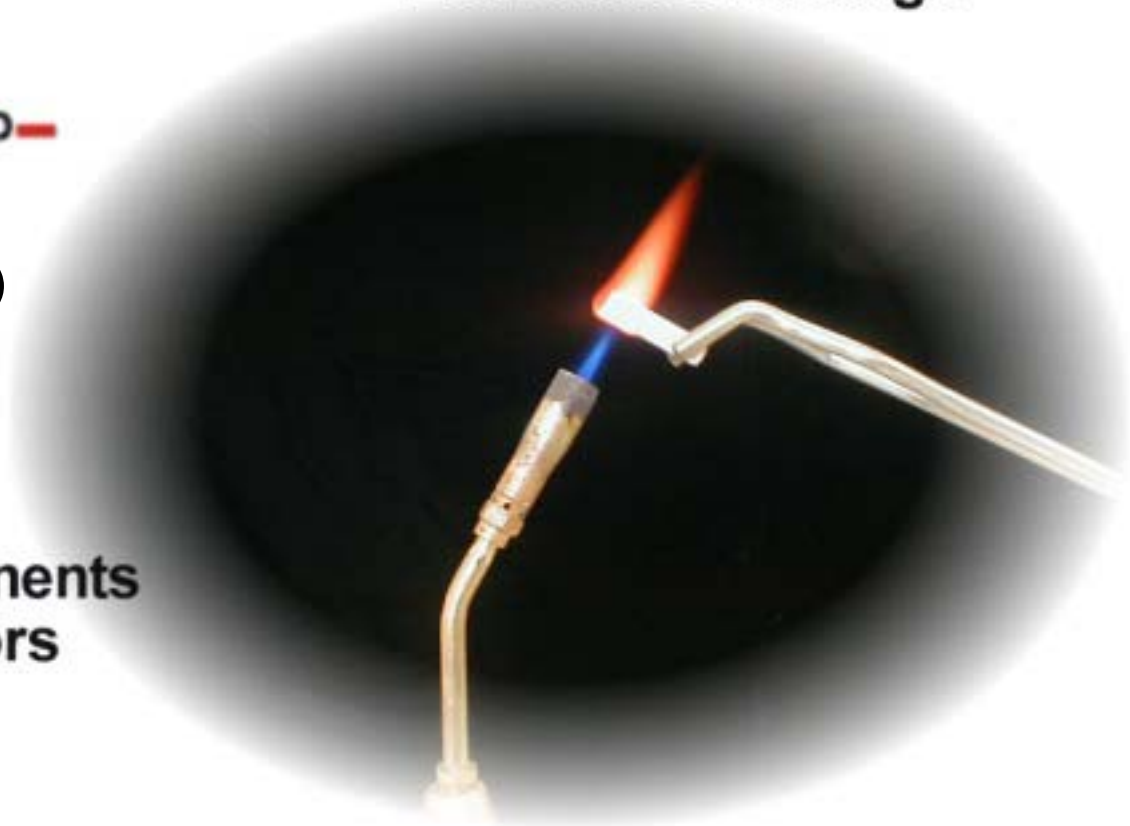
poly(sialate-siloxo)

## Features

- Castable
- Low temperature cure (60°)
- Low cure shrinkage

## Applications

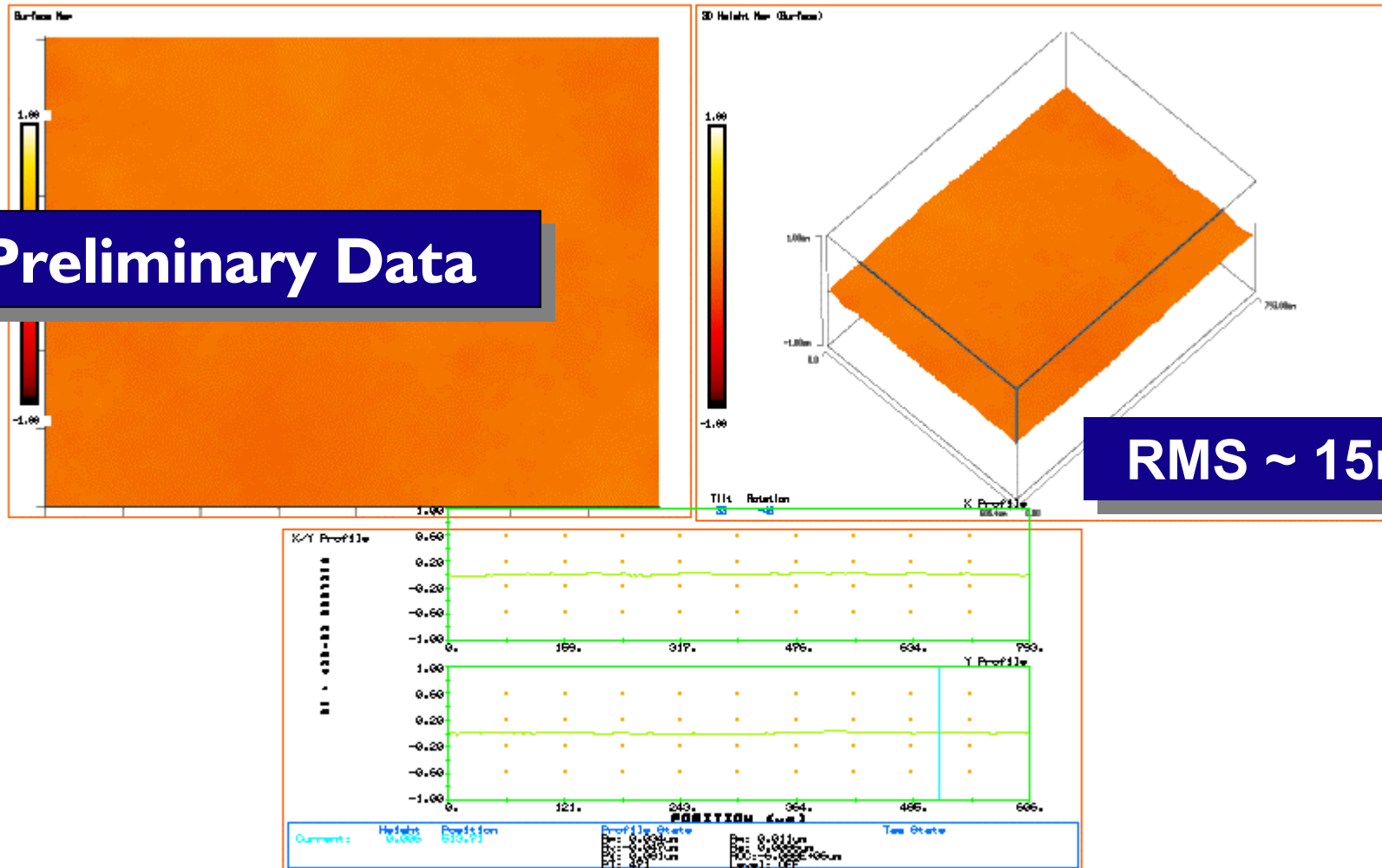
- Propulsion components
- Space-based mirrors
- Secure electronics





**Preliminary Data**

**RMS ~ 15nm**



|                     |   |                                 |                        |                       |  |  |
|---------------------|---|---------------------------------|------------------------|-----------------------|--|--|
| Title : Polysialate |   | Statistics of Surface: AT-P5028 |                        |                       |  |  |
| Part ID : P5028     | ADE/PHASE SHIFT<br>MapVue EX - Surface Mapping Software<br>Version 6.35 (c) 1985-2001 | Rp: 0.11um                      | Rq: 0.02um             | Area: 753.00x506.41um |  |  |
| Customer :          |   | Rv: -0.11um                     | Rz: 0.02um             | Mag : 10.1            |  |  |
| Operator : AT       |   | Pt: 0.22um                      | Rsk: -0.30             | DATE: 04-24-2002      |  |  |
| Field-5 :           |   | PT: 345763                      | Rku: 3.16              | TIME: 09:51:41        |  |  |
| Field-6 :           |   |                                 | Taxes Subtracted: T114 |                       |  |  |
| Comment :           |   |                                 |                        |                       |  |  |

- **CRG Achieved Phase I Gossamer Objectives**
  - Demonstrated LCP Film Broadband Reflector
  - Demonstrated LCP Membrane Narrowband Reflector
- **Other CRG Technologies Support Future Space-Based Imaging Applications**
  - Shape Memory Polymers
  - Dynamic Modulus Composites
  - Multi-Functional Composites
  - Composite Mirrors
  - High-Performance Syntactic Composites
  - Polysialate Composites